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(71) Applicant: **TOYOTA JIDOSHA KABUSHIKI KAISHA**
**Aichi-ken 471-8571 (JP)**

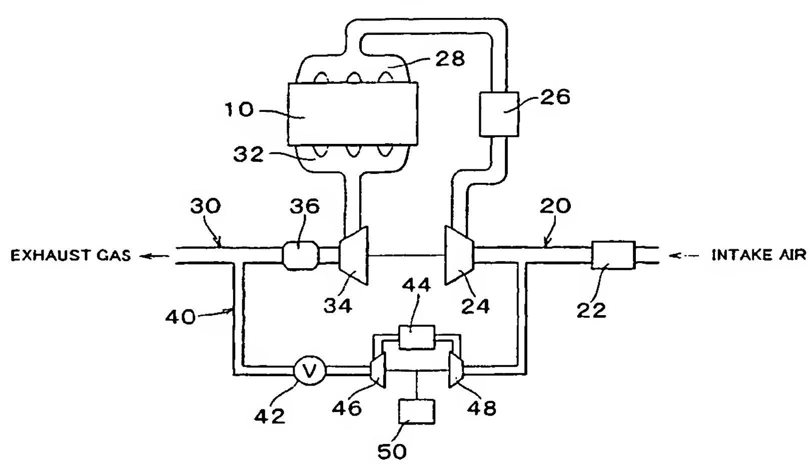
(72) Inventors:
- **Shibata, Masahito,**
**Toyota Jidosha Kabushiki Kaisha**
**Toyota-shi, Aichi-ken 471-8571 (JP)**
- **Otsubo, Yasuhiko,**
**Toyota Jidosha Kabushiki Kaisha**
**Toyota-shi, Aichi-ken 471-8571 (JP)**
- **Shimizu, Sadanobu,**
**Toyota Industries Corporation**
**Kariya-shi, Aichi-ken (JP)**

(74) Representative:
**Leson, Thomas Johannes Alois, Dipl.-Ing.**
**Tiedtke-Bühling-Kinne & Partner GbR,**
**TBK-Patent,**
**Bavariaring 4**
**80336 München (DE)**

(54) **Exhaust gas recirculation system for internal combustion engine**

(57) An EGR system for an internal combustion engine includes a cooling means (44) disposed in an EGR passage (40) for cooling an EGR gas, an EGR-gas compressor (46) disposed in the EGR passage (40) upstream of the cooling means (44) for compressing the EGR gas, an EGR-gas turbine (48) disposed in the EGR passage (40) downstream of the cooling means (44) for expanding the EGR gas, and driving means (50) for driving the EGR-gas compressor and turbine (46),(48). The EGR passage (40) extends in communication between the exhaust passage (30) downstream of a turbine (34) of a supercharger for the engine and the intake air passage (20) upstream of a compressor (24) of the supercharger. When the EGR system is equipped with a diesel particulate filter (36), the EGR passage (40) is connected to a portion of the exhaust passage (30) downstream of the particulate filter (36).

FIG. 1

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## Description

## BACKGROUND OF THE INVENTION

### 1.Field of the Invention

**[0001]** The invention relates to an EGR (Exhaust Gas Recirculation) system for an internal combustion engine which is operable to recirculate at least a portion of an exhaust gas from an exhaust system to an intake air system of the engine, for the purpose of reducing nitrogen oxides (NOx) emissions.

### 2.Description of Related Art

**[0002]** Exhaust gas recirculation (EGR) is performed as one of conventional techniques for purifying exhaust gas discharged from an internal combustion engine for a motor vehicle. According to the EGR technique, at least a portion of the exhaust gas containing $CO_2$, which has a heat capacity larger than that of $N_2$ in the atmosphere, is reintroduced into a combustion chamber of the engine so as to lower a combustion temperature and, thus, to decrease an amount of nitrogen oxides (NOx) produced by the combustion. The EGR technique is widely used for reducing NOx emissions in diesel engines in which combustion is performed in the presence of excessive air. The EGR, however, is likely to increase an amount of smoke emitted in the exhaust gas. The engine is provided with an EGR system including an exhaust gas recirculation passage (EGR passage) for communication between an exhaust passage and an intake air passage, and an EGR valve disposed in the EGR passage. The operation of the EGR system is controllable by suitably opening and closing the EGR valve.

**[0003]** In the EGR system, at least a portion of the exhaust gas is reintroduced into an intake air of the engine as described above. Reintroducing the expanded exhaust gas at a high temperature into the intake air may decrease an amount of new air fed to the engine, and increase the combustion chamber temperature. As a result, the amount of NOx cannot be sufficiently reduced, and the amount of smoke is increased. The aforementioned problem may be solved by providing the EGR system with an EGR cooler adapted to cool the exhaust gas flowing from the exhaust passage to the intake air. Hereinafter, the exhaust gas flowing from the exhaust passage to be reintroduced into the intake air is referred to as an "EGR gas".

**[0004]** In the EGR cooler, however, the lower the temperature of the EGR gas becomes, the more a mist of the EGR gas is generated. Particles of the resultant mist adhere to the inside of the EGR cooler, and clog the EGR cooler. Particularly, in the state where the EGR gas is at a relatively lower temperature than usual, e.g., during a low-load engine operation, its temperature is further decreased in the EGR cooler. This may further promote clogging of the EGR cooler with the mist particles.

**[0005]** The EGR system is operable to reintroduce the EGR gas into the intake air with the aid of a pressure difference between an exhaust pressure and an intake pressure. In this respect, the EGR cooler disposed in the EGR passage serves to resist the EGR gas flowing through the EGR passage, thus decreasing the flow rate of the EGR gas. Particularly in the internal combustion engine with a supercharger for the engine, since the exhaust pressure is increased as well as the intake air pressure, the pressure difference therebetween is reduced. In this case, the reduction of the pressure difference by the EGR cooler reaches the level that cannot be ignored. Meanwhile, in order to satisfy the requirement of the recent trend of further improvement in the exhaust-gas purifying capacity of the engine, the EGR is required to be performed even at a high intake air pressure during a high-load engine operation. Therefore, the EGR system generally needs to take a measure such that a sufficient pressure difference between the exhaust pressure and the intake pressure can be ensured.

**[0006]** In the EGR system, it is further required to purify the EGR gas so as to prevent clogging of the EGR valve, EGR cooler and compressor of the turbocharger, and contamination of the inside of the internal combustion engine.

## SUMMARY OF THE INVENTION

**[0007]** It is an object of the invention to provide an exhaust gas recirculation (EGR) system for an internal combustion engine, which is capable of reducing an amount of mist particles generated in an EGR cooler, allowing a large amount of EGR gas to be recirculated by keeping a pressure difference between an exhaust pressure and an intake air pressure within a broader range of engine operating conditions including a high-load engine operating condition, and permitting recirculation of purified EGR gas.

**[0008]** To accomplish the above and/or other objects, the principle of the invention provides an EGR system for an internal combustion engine provided with cooling means disposed in an EGR passage, for cooling an EGR gas, an EGR-gas compressor which is disposed in the EGR passage upstream of the cooling means and is operable to compress the EGR gas, an EGR-gas turbine which is disposed in the EGR passage downstream of the cooling means and is operable to expand the EGR gas, and driving means for driving the EGR-gas compressor and the EGR-gas turbine.

**[0009]** According to one preferred form of the invention, the EGR passage communicates an exhaust passage downstream of a turbine of a supercharger for the internal combustion engine with an intake passage upstream of a compressor of the supercharger.

**[0010]** According to another preferred form of the invention, the EGR passage communicates an exhaust passage downstream of a particulate filter with an intake

passage upstream of a compressor of a supercharger for the internal combustion engine.

## BRIEF DESCRIPTION OF THE DRAWINGS

**[0011]**

Fig. 1 is a schematic diagram of an internal combustion engine incorporating an EGR system according to one preferred embodiment of the invention;
Fig. 2A is a graph showing a change in an EGR gas temperature in a conventional EGR system;
Fig. 2B is a graph showing a change in an EGR gas temperature in the EGR system of the invention;
Fig. 3 is a schematic diagram of a first embodiment of driving means for driving an EGR-gas compressor and an EGR-gas turbine incorporated in the EGR system of the invention;
Fig. 4 is a schematic diagram of a second embodiment of the driving means for driving the EGR-gas compressor and turbine incorporated in the EGR system of the invention;
Fig. 5 is a schematic diagram of a third embodiment of the driving means for driving the EGR-gas compressor and turbine incorporated in the EGR system of the invention; and
Fig. 6 is a schematic diagram of a fourth embodiment of the driving means for driving the EGR-gas compressor and turbine incorporated in the EGR system of the invention.

## DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

**[0012]** Preferred embodiments of the invention will be described with reference to the accompanying drawings.

**[0013]** Fig. 1 schematically shows a diesel engine with a supercharger incorporating an EGR system according to the preferred embodiment of the invention. The diesel engine includes an engine body 10 provided with a plurality of cylinders each performing combustion therein, and an intake air passage 20 for supplying an intake air required for the combustion to the engine body 10. Described in detail, the engine is provided with the intake air passage 20, an air cleaner 22, a compressor 24 of the supercharger, an intercooler 26, and an intake manifold 28. The intake air supplied to the engine body 10 through the intake air passage 20 is filtered by the air cleaner 22, compressed by the compressor 24, cooled by the intercooler 26, and then introduced to the intake manifold 28. The intake manifold 28 serves to deliver the intake air to the plurality of cylinders of the engine body 10. An exhaust gas generated in each of the cylinders is discharged through an exhaust passage 30. Specifically, the exhaust passage 30 is connected with an exhaust manifold 32, a turbine 34 of the supercharger and a diesel particulate filter (DPF) 36. The exhaust gas discharged from each cylinder is collected in the exhaust manifold 32. The collected exhaust gas is forced to pass through the turbine 34 that is connected coaxially with the compressor 24, purified by the DPF 36, and then finally discharged.

**[0014]** The diesel engine is adapted to perform combustion in the presence of excessive air. Accordingly, emissions of HC(hydrocarbons) and CO(carbon monoxide) as incomplete combustion components are reduced. On the contrary, however, emissions of particulates and nitrogen oxides (NOx) produced by a reaction between nitrogen in the atmosphere and unburned oxygen are increased in the exhaust gas. The emitted particulates are formed as a composite of black smoke (dry soot) as a major component, soluble organic fraction (SOF), sulfates (sulfate mists) and the like. Therefore the particulate-emission rate cannot be reduced by merely improving combustion capacity of the internal combustion engine. Then the DPF 36 is provided in the exhaust passage 30 to lower the particulate emission by trapping the particulates therein.

**[0015]** The diesel engine of the invention is equipped with an EGR system intended to reduce the NOx emissions. The EGR system includes an EGR passage 40 extending between the exhaust passage 30 and the intake air passage 20 so as to circulate the exhaust gas for reintroducing a portion of the exhaust gas, i.e., an EGR gas to the intake air. An EGR valve 42 is provided in the EGR passage 40 to adjust a flow rate of the EGR gas to be recirculated. An EGR cooler 44 is also provided in the EGR passage 40 for cooling the EGR gas. In the present embodiment, the EGR cooler 44 may be formed as a heat exchanger using cooling water.

**[0016]** In the conventional EGR system, as shown in Fig. 2A, when the EGR gas passes through the EGR cooler 44, the EGR gas temperature decreases to be lower than a temperature limit below which the mist is generated. Therefore, the EGR gas mist is generated in the EGR cooler 44 and the mist particles adhere to the inside thereof. As a result, the EGR cooler 44 of the EGR gas is clogged. The aforementioned clogging problem may be solved by providing an EGR-gas compressor 46 in the EGR passage 40 upstream of the EGR cooler 44 so as to temporarily increase the temperature of the EGR gas flowing into the EGR cooler 44. As is understood from the graph of Fig. 2B, when the EGR gas passes through the EGR cooler 44, the EGR gas temperature is effectively kept higher than the limit temperature, thus reducing an amount of the mist particles of the EGR gas generated in the EGR cooler 44.

**[0017]** The EGR system of the present embodiment further includes an EGR-gas turbine 48 disposed in the EGR passage 40 downstream of the EGR cooler 44. The EGR-gas turbine 48 is adapted to expand the EGR gas delivered from the EGR cooler 44. Referring to Fig. 2B, expanding the EGR gas may decrease the EGR-gas temperature to the degree corresponding to a tem-

perature increment of the EGR-gas compressed by the EGR-gas compressor 24. Since the EGR-gas turbine 48 rotates at a high revolution speed, no clogging occurs.

**[0018]** In the EGR system of this embodiment, the temperature of the EGR gas is increased by compressing the EGR gas in the EGR-gas compressor 46 so as to prevent generation of the mist particles in the EGR cooler 44. The temperature increment of the EGR-gas compressed by the EGR-gas compressor 46 can be effectively compensated by a temperature decrement of the EGR-gas expanded by the EGR-gas turbine 48. In the end, the EGR system of the present embodiment makes it possible to recirculate the EGR gas cooled by the EGR cooler 44 to the intake air passage 20. Therefore, volumetric efficiency of the engine can be enhanced, and output characteristics, fuel economy, and exhaust gas purifying capacity of the engine can be improved. It should be appreciated that the EGR-gas turbine 48 and the EGR-gas compressor 46 are coaxially disposed with each other and are mechanically driven by driving means 50 such that the EGR gas increasingly flows through the EGR passage 40 without using an intake air throttle valve nor exhaust throttle valve.

**[0019]** Fig. 3 shows a first embodiment of the driving means 50 for driving the EGR-gas compressor 46 and the EGR-gas turbine 48. According to the first embodiment of the driving means 50, at least one of rotating members of the internal combustion engine, e.g., camshaft, timing belt, pulley, is utilized to drive the EGR-gas compressor 46 and the EGR-gas turbine 48. Fig. 4 shows a second embodiment of the driving means 50 in which the driving means 50 is embodied by utilizing a power of the exhaust gas discharged from the engine. Namely, rotation of the supercharger consisting of the turbine 34 and the compressor 24 is utilized to drive the EGR-gas compressor 46 and the EGR-gas turbine 48.

**[0020]** Fig 5 shows a third embodiment of the driving means 50 in which an electric motor independent of the internal combustion engine is utilized to drive the EGR-gas compressor 46 and the EGR-gas turbine 48. Fig. 6 shows a fourth embodiment of the driving means 50 which is embodied by utilizing a lubrication system of the internal combustion engine. That is, the EGR-gas compressor 46 and the EGR-gas turbine 48 are driven by a power of oil jet.

**[0021]** Meanwhile, the EGR technique provides a recirculation of the exhaust gas into the intake air, by utilizing a pressure difference between an exhaust pressure and an intake air pressure. In this respect, the EGR cooler 44 functions as a resistance to the EGR gas flowing through the EGR passage 40, and reduces the pressure difference between the exhaust pressure and the intake air pressure. To compensate such decrease in the pressure difference, the EGR system of the present embodiment is arranged such that the EGR passage 40 extends in communication between the exhaust passage 30 downstream of the turbine 34 of the supercharger and the intake air passage 20 upstream of the compressor 24 of the supercharger, as is apparent from Fig. 1. Namely, the pressure of the portion downstream of the turbine 34 is lower than that of the portion upstream of the turbine 34. However, the intake air passage upstream of the compressor 24 is at a low pressure corresponding to be the atmospheric pressure, making it possible to keep sufficient pressure difference. Therefore, the EGR system of the embodiment may be operated during a high-load engine operation at a high intake air pressure.

**[0022]** Referring to Fig. 1, the EGR passage 40 extends in communication between the exhaust passage 30 downstream of the DPF 36 and the intake air passage 20 EGR-gas upstream of the compressor 24 of the supercharger. This arrangement makes it possible to perform recirculation of purified EGR gas, thus preventing conventionally experienced problems such as clogging of the EGR valve 42, the EGR cooler 44 and the compressor 24 of the supercharger, and contamination of the inside of the internal combustion engine.

**[0023]** As is understood from the foregoing description, the EGR system of the invention is capable of performing the EGR gas by preventing generation of the mist particles of the EGR gas in the EGR cooler, and is operable of performing a desired amount of EGR gas within a broader range of engine operating conditions including the high-load engine operation condition. Further, the EGR system of the invention makes it possible to recirculate purified EGR gases, thus preventing problems of clogging of the EGR system components and the internal combustion engine or the like.

**[0024]** The EGR system for an internal combustion engine according to the present invention includes a cooling means 44 disposed in an EGR passage 40 for cooling an EGR gas, an EGR-gas compressor 46 disposed in the EGR passage 40 upstream of the cooling means 44 for compressing the EGR gas, an EGR-gas turbine 48 disposed in the EGR passage 40 downstream of the cooling means 44 for expanding the EGR gas, and driving means 50 for driving the EGR-gas compressor and turbine 46,48. The EGR passage 40 extends in communication between the exhaust passage 30 downstream of a turbine 34 of a supercharger for the engine and the intake air passage 20 upstream of a compressor 24 of the supercharger. When the EGR system is equipped with a diesel particulate filter 36, the EGR passage 40 is connected to a portion of the exhaust passage 30 downstream of the particulate filter 36.

## Claims

1. An EGR system for an internal combustion engine, comprising:

   cooling means (44), disposed in an EGR passage (40), for cooling an EGR gas;

an EGR-gas compressor (46) which is disposed in the EGR passage (40) upstream of the cooling means (44) and is operable to compress the EGR gas;
an EGR-gas turbine (48) which is disposed in the EGR passage (40) downstream of the cooling means (44) and is operable to expand the EGR gas; and
driving means (50) for driving the EGR-gas compressor (46) and the EGR-gas turbine (48).

2. An EGR system according to claim 1, wherein the EGR passage (40) communicates an exhaust passage (30) downstream of a turbine (34) of a supercharger for the internal combustion engine with an intake passage (20) upstream of a compressor (24) of the supercharger.

3. An EGR system according to claim 1 or 2, wherein the EGR passage (40) communicates an exhaust passage (30) downstream of a particulate filter (36) with an intake passage (20) upstream of a compressor (24) of a supercharger for the internal combustion engine.

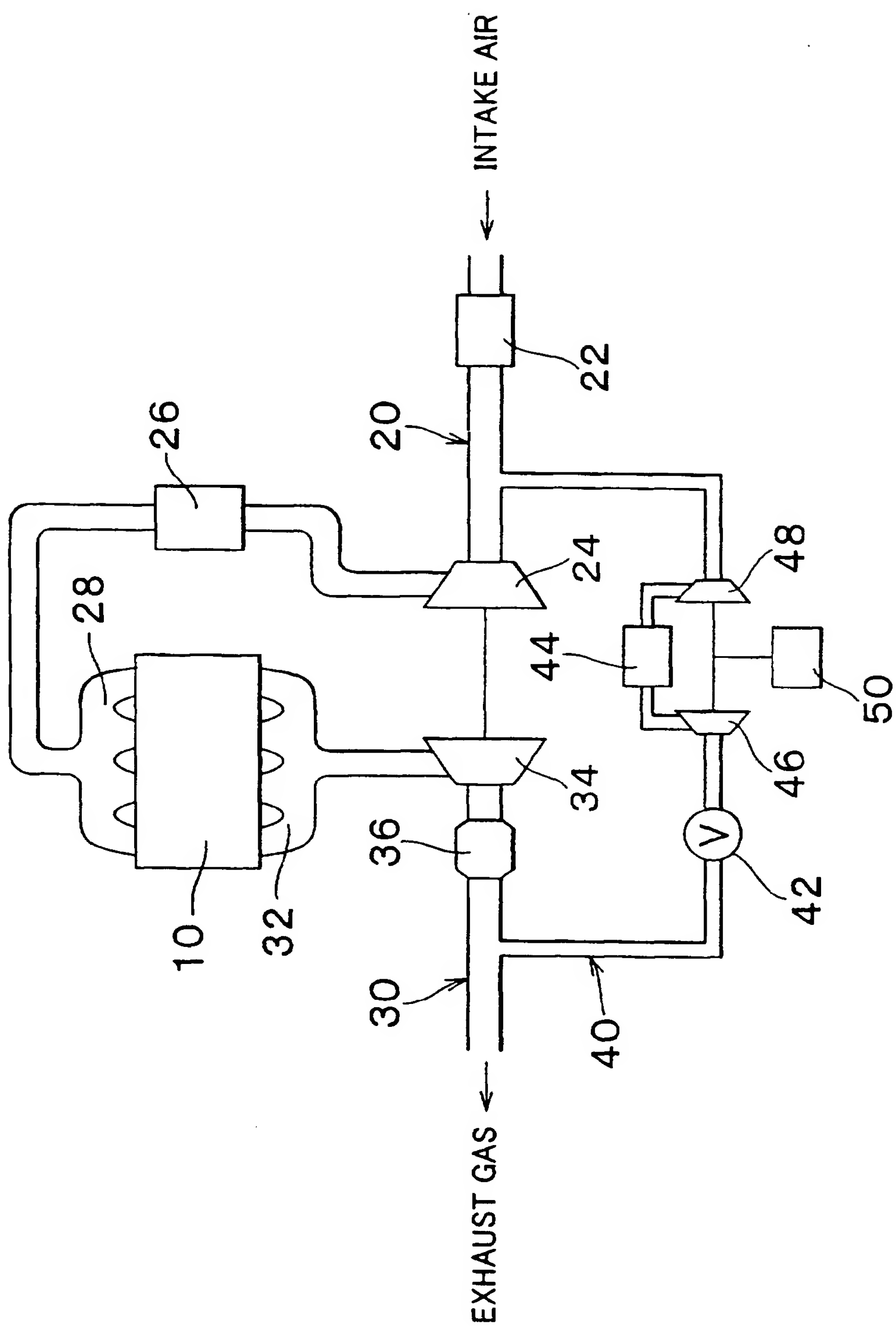
4. An EGR system according to any one of claims 1 to 3, wherein the driving means (50) is operatively connected to a rotating member of the internal combustion engine.

5. An EGR system according to any one of claims 1 to 3, wherein the driving means (50) is operatively connected to a supercharger for the internal combustion engine.

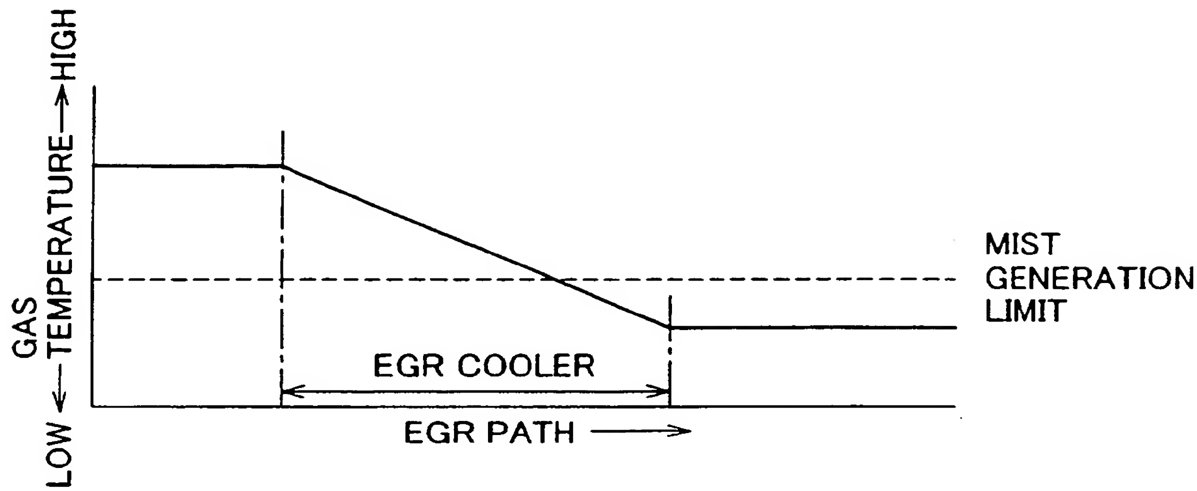
6. An EGR system according to any one of claims 1 to 3, wherein the driving means (50) comprises a motor that is provided independently of the internal combustion engine.

7. An EGR system according to any one of claims 1 to 3, wherein the driving means (50) utilizes a lubrication system of the internal combustion engine.

FIG. 1


INTAKE AIR
EXHAUST GAS
10
20
22
24
26
28
30
32
34
36
40
42
44
46
48
50
V

# F I G. 2A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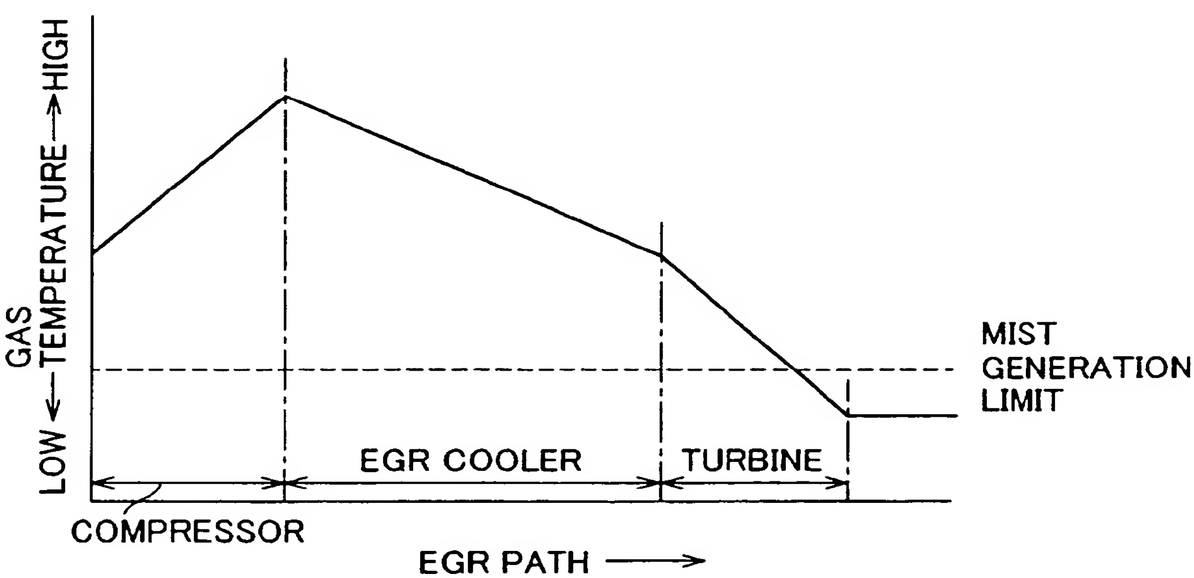
MIST GENERATION LIMIT
EGR COOLER
EGR PATH ——→

# F I G. 2B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MIST GENERATION LIMIT
EGR COOLER
TURBINE
COMPRESSOR
EGR PATH ——→

FIG. 3

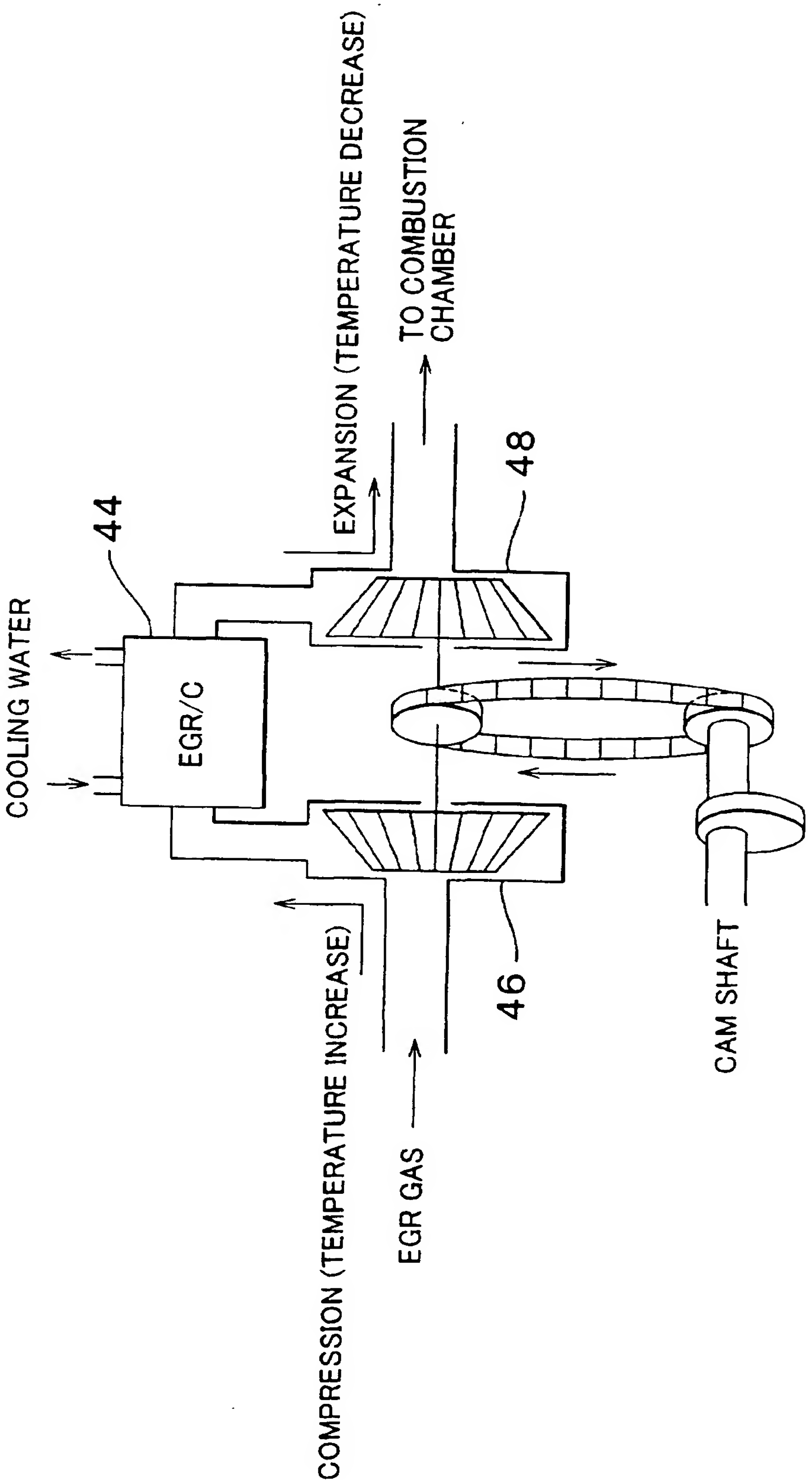

COOLING WATER
EGR/C
44
EXPANSION (TEMPERATURE DECREASE)
TO COMBUSTION CHAMBER
48
COMPRESSION (TEMPERATURE INCREASE)
EGR GAS
46
CAM SHAFT

FIG. 4

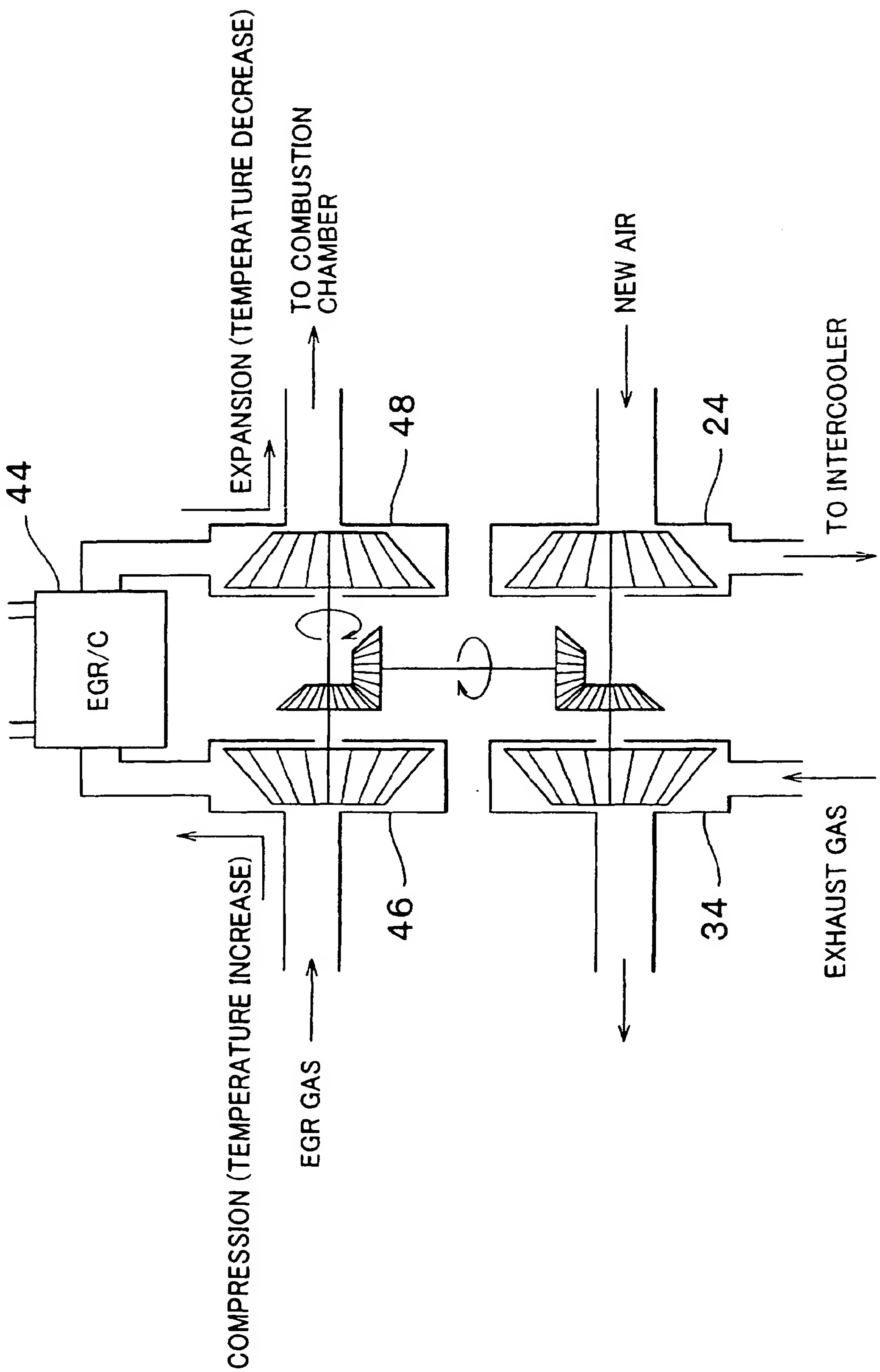

44
EGR/C
EXPANSION (TEMPERATURE DECREASE)
TO COMBUSTION CHAMBER
48
NEW AIR
24
TO INTERCOOLER
COMPRESSION (TEMPERATURE INCREASE)
EGR GAS
46
34
EXHAUST GAS

FIG. 5

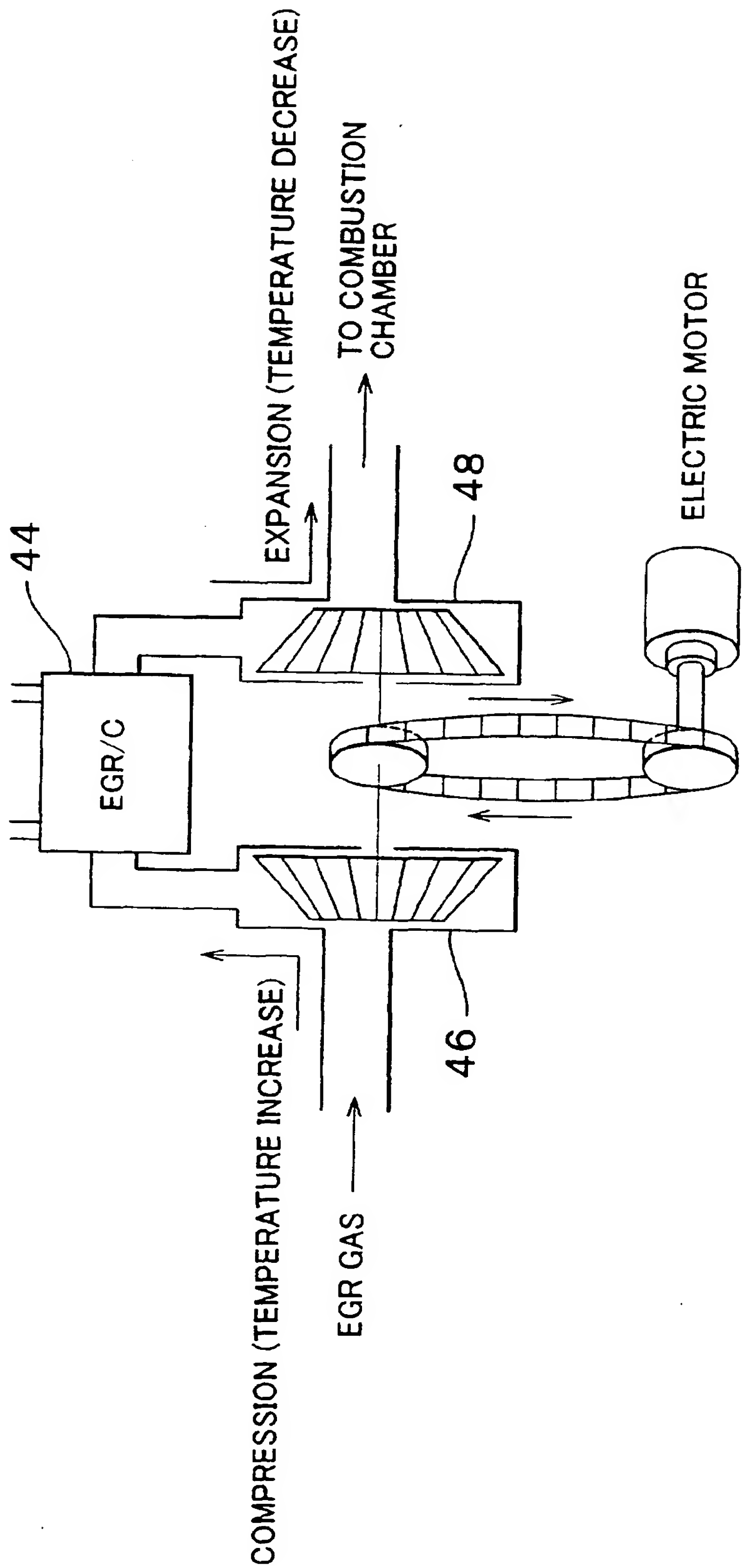
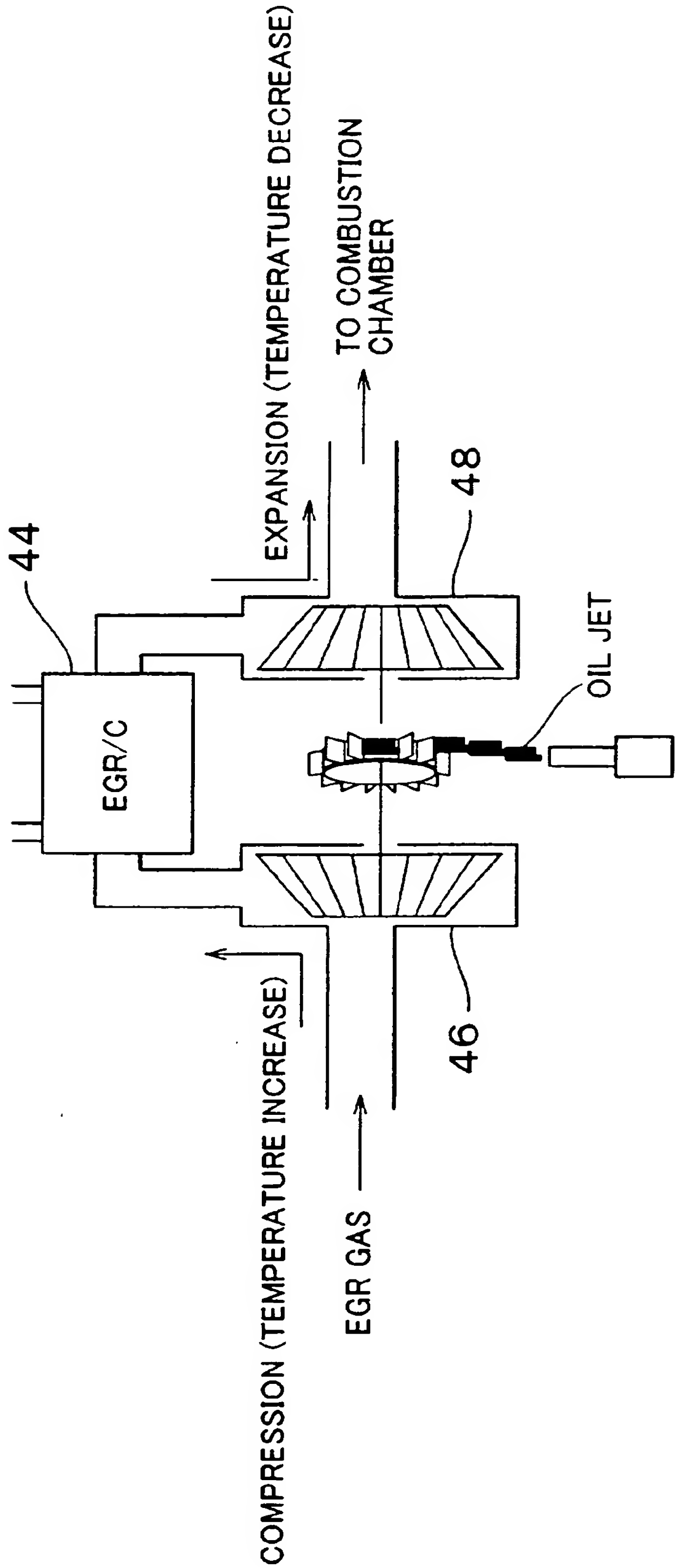

EXPANSION (TEMPERATURE DECREASE)
TO COMBUSTION CHAMBER
ELECTRIC MOTOR
44
48
EGR/C
46
COMPRESSION (TEMPERATURE INCREASE)
EGR GAS

FIG. 6


44
EGR/C
EXPANSION (TEMPERATURE DECREASE)
TO COMBUSTION CHAMBER
48
OIL JET
COMPRESSION (TEMPERATURE INCREASE)
EGR GAS
46

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(72) Inventors:
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**Toyota Jidosha Kabushiki Kaisha**
**Toyota-shi, Aichi-ken 471-8571 (JP)**
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**Toyota Jidosha Kabushiki Kaisha**
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**Leson, Thomas Johannes Alois, Dipl.-Ing.**
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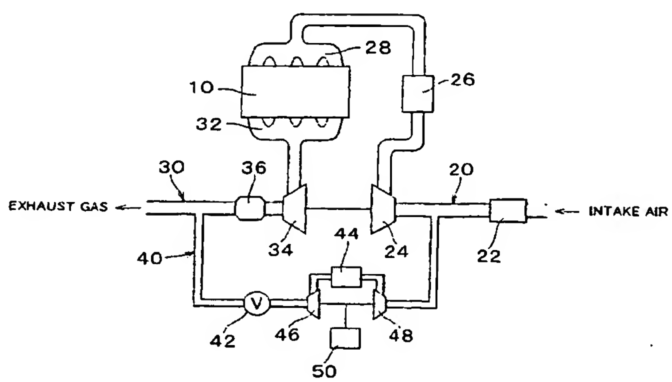
FIG. 1

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# EUROPEAN SEARCH REPORT

Application Number
EP 01 12 1561

## DOCUMENTS CONSIDERED TO BE RELEVANT

| Category | Citation of document with indication, where appropriate, of relevant passages | Relevant to claim | CLASSIFICATION OF THE APPLICATION (Int.Cl.7) |
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TECHNICAL FIELDS SEARCHED (Int.Cl.7)
F02M

The present search report has been drawn up for all claims

| Place of search | Date of completion of the search | Examiner |
|---|---|---|
| THE HAGUE | 27 February 2003 | Raposo, J |

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
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EPO FORM 1503 03.82 (P04C01)

## ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 01 12 1561

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27-02-2003

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